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EXPERIMENTAL STUDY OF TWO-BODY AND QUASI-TWO-BODY REACTIONS IN K^-n INTERACTIONS AT 3 GeV/c

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Abstract: The main purpose of this article is the presentation of all data accumulated in the study of the (quasi) two-body reactions produced in K^-n interactions at 3 GeV/c. From the general features of the differential cross sections, as well as from the smallness of exotic amplitudes in the t -channel it appears that the forward and backward scatterings should be well described even at this energy by t - and u -channel interactions.

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1. INTRODUCTION

In this paper we report cross sections and angular distributions of most of the two-body and quasi two-body reactions in K^-n interactions at 3 GeV/c. The results were obtained in a 6.8 events/ μ b/nucleon experiment with the 81 cm Saclay deuterium bubble chamber exposed to an electrostatically separated 3 GeV/c K^- beam at the CERN Proton-Synchrotron. Experimental details, cross sections and the analysis of some reactions were already the subject of a number of publications [1–12]. The main purpose of this paper is to collect all the experimental results on (quasi) two-body reactions found in this experiment and to present them in a more unified way together with the corresponding ones obtained some years ago in a 3 GeV/c K^-p experiment [13].

A (quasi) two-body reaction will be defined as

$$K^-N \rightarrow MB, \quad (1)$$

where M is a meson or a mesonic resonance, while B is a baryon or a baryonic resonance*. Processes of this type, described in terms of s -, t - or u -channel interaction (fig. 1), are responsible for a large fraction of the K^-n cross section at 3 GeV/c.



Fig. 1. Definitions of the s -, t - and u -channel for reaction (1).

The general experimental procedure used to separate these reactions is discussed in sect. 2. In sect. 3 the tables of total and differential cross sections are presented as well as density matrix elements and polarization results. The gross features of the differential cross sections are discussed in sect. 4 where a t -channel isospin decomposition is done for some reactions with the help of the K^-p data. No other detailed analysis and interpretation will be given in this compilation paper; they may be found in the preceding papers.



* We shall not discuss coherent interactions on deuterium [14].

2. EXPERIMENTAL

Experimental details, including cross section normalizations, deuterium problems, separation of various kinematical ambiguities and separation of partial cross sections, have been described in ref. [1]*. For quasi two-body processes, in addition to the separation problems mentioned in ref. [1], problems arise in determining the percentages of resonance production and of background. The percentage of resonance production was determined either by using one-dimensional effective mass plots and assuming Breit-Wigner formulae and relativistic phase space or by analysing a two-dimensional mass plot.

The angular distributions were obtained by selecting events in the peak of the resonance. A non resonating background was estimated from the analysis of the events in the regions close to the peak. The errors in the angular distributions are only statistical; they include errors arising from background subtraction. Normalization errors are included only in the total cross sections (table 1).

The c.m. scattering angle, θ^* , was defined as the angle between the incident K^- and the outgoing meson or mesonic resonance, in the rest system of all the outgoing particles, excluding the spectator proton. The invariant four-momentum transfer squared t and u have been deduced from θ^* by assuming a fixed K^-n c.m. energy of 2.616 GeV and a fixed mass for the resonances produced.

In order to evaluate the differential production cross sections for quasi two-body reactions, the various decay modes have to be added. This was done when possible; otherwise the known decay branching ratios were used [15] to evaluate the decay channels which were not observed.

3. RESULTS

3.1. Total cross sections

The experimental results concerning the cross sections of (quasi) two-body reactions are presented in table 1. The reactions are classified according to the spin parity of the final state particles, and in a given column according to the baryon hypercharge. For each reaction, the backward ($\cos \theta^* < 0$), forward ($\cos \theta^* > 0$) and total cross sections are presented.

Table 2, from ref. [13], shows the corresponding results for K^-p interactions. In reaction (1) the pure $I = 1$ isospin final states, such as $M(I=1) B(I=0)$ and $M(I=\frac{1}{2}) B(I=\frac{3}{2})$, should be produced with cross sections related by charge independence. These relations are generally well verified as can be checked from tables 1 and 2.

* As seen in this reference, the total K^-n cross section determined in this experiment amounts to 21.8 ± 2 mb.

Table 1
Cross sections for K⁻n (quasi) two-body reactions at 3 GeV/c

	$0^{-\frac{1}{2}+}$	$1^{-\frac{1}{2}+}$	$0^{-\frac{3}{2}+}$	$1^{-\frac{3}{2}+}$	Miscellaneous
162 ± 40 K ⁻ n	3240 ± 900	110 ± 20 K [*] n	66 ± 15 $\overline{K}^0\Delta^-$	120 ± 15 $\overline{K}^{*0}\Delta^-$	K [*] -(1400)n 415±115
55 ± 13 $\pi^- \Sigma^0$	105 ± 18 160 ± 22				16 ± 10 $\pi^- \Lambda^0(1405)$
67 ± 17 $\pi^- \Lambda^0$	233 ± 30 300 ± 32	66 ± 22 $\rho^- \Lambda^0$			152 ± 25 305 ± 30
42 ± 12 $\pi^0 \Sigma^-$	88 ± 16 130 ± 20	28 ± 7 $\rho^0 \Sigma^-$	19 ± 10 $\pi^0 \Sigma^-(1385)$	33 ± 6 $\rho^- \Sigma^0(1385)$	51 ± 39 $\pi^- \Lambda(1690)$
14 ± 4 $\eta^0 \Sigma^-$	36 ± 6 50 ± 7	27 ± 7 $\omega^0 \Sigma^-$	31 ± 8 $\eta^0 \Sigma^-(1385)$	40 ± 10 $\omega^0 \Sigma^-(1385)$	49 ± 45 100 ± 60
<2 $\eta^0 \Sigma^-$	70 ± 20 70 ± 20	2 ± 2 $\phi \Sigma^-$ -a	47 ± 10 49 ± 10	4 ± 2 $\phi \Sigma^-(1385)$	$\pi^- \Sigma^0(1765)$ <130
45 ± 9 K ⁰ Ξ^-	4 ± 4 49 ± 9	22 ± 8 K [*] 0 Ξ^-	8 ± 4 30 ± 9	40 ± 10 44 ± 10	220 ± 28 $\pi^- \Lambda(1815)$
					350 ± 270 $\pi^- \Sigma^0(1915)$
					250 ± 210 600 ± 350
					140 ± 56 $\pi^- \Lambda(2100)$
					70 ± 40 210 ± 70
					B ⁻ Λ^0 102± 26

The table gives for each Meson-Baryon (MB) final state considered: the backward σ_B ($\cos \theta^* < 0$) the forward σ_F ($\cos \theta^* > 0$) and the total cross section σ_{tot} (in μb) in the format:

σ_B σ_F

MB σ_{tot}

a m : cross section has been determined from the $V\pi V\pi$ decay of the ϕ meson (ref. [7]) and the branching fraction $\phi \rightarrow K^+ K^- / \phi \rightarrow \text{total} =$

Table 2
Cross section for K^-p (quasi) two-body reactions at 3 GeV/c (ref. [13])

$0-\frac{1}{2}^+$	$1-\frac{1}{2}^+$	$0-\frac{3}{2}^+$	$1-\frac{3}{2}^+$	Miscellaneous
56 ± 20 K^-p	39 ± 10 K^-p	25 ± 10 $K^-\Delta^+$	50 ± 20 $K^*\Delta^+$	300 ± 120 350 ± 135
12 ± 4 $\bar{K}^0n$	56 ± 14 $\bar{K}^*0n$	20 ± 10 $\bar{K}^0\Delta^0$ a	210 ± 100 230 ± 100	
44 ± 6 $\pi^-\Sigma^+$	5 ± 5 $\rho^-\Sigma^+$	11 ± 4 $\pi^-\Sigma^+(1385)$	67 ± 7 78 ± 8	53 ± 10 64 ± 11
37 ± 7 $\pi^0\Lambda$	38 ± 7 $\rho^0\Lambda$			9 ± 3 $\pi^0\Lambda(1405)$
9 ± 3 $\eta^0\Lambda$	47 ± 5 $\omega^0\Lambda$			116 ± 19 $\pi^0\Lambda(1520)$
5 ± 3 $\eta'^0\Lambda$	3 ± 2 $\phi\Lambda$ b			41 ± 13 $\omega^0\Lambda(1520)$
	24 ± 8 $\rho^0\Sigma^0$		0 ± 4 $\rho^0\Sigma^0(1385)$	30 ± 6 30 ± 7
24 ± 6 $\pi^+\Sigma^-$	12 ± 3 $\rho^+\Sigma^-$	10 ± 2 $\pi^+\Sigma^-(1385)$	12 ± 2 22 ± 3	5 ± 3 12 ± 4
20 ± 4 $K^0\Xi^0$	12 ± 5 32 ± 9	9 ± 3 $K^0\Xi^{*0}$	8 ± 3 17 ± 4	4 ± 2 7 ± 3
17 ± 3 $K^+\Xi^-$	13 ± 3 $K^{*+}\Xi^-$	2 ± 2 $K^+\Xi^{*-}$	2 ± 2 4 ± 3	13 ± 9 13 ± 9

The notation is the same as for table 1.

a From ref. [17].

b This cross section has been determined from the K^+K^- decay of the Φ -meson (ref. [18]) and the branching fraction $\Phi \rightarrow K^+K^-/\Phi \rightarrow \text{total} = 0.455$ (ref. [15]).

Table 3
Total and differential cross section for the reactions $K^-n \rightarrow M(0^-) B(\frac{1}{2}^+)$

Final state	K^-n	0^-	$\frac{1}{2}^+$	$\pi^-\Sigma^0 + \pi^0\Sigma^-$	$\eta\Sigma^-$	$K^0\Xi^-$
σ total (μb)	3400 ± 900	300 ± 32	290 ± 30	50 ± 7	49 ± 9	
$\cos\theta^*$		$d\sigma/d\Omega$ ($\mu\text{b/sr}$)				
0.9625		188.9 ± 35.5	158.6 ± 30.1			
0.95				27.4 ± 6.0		
0.9375	2900 ± 350	165.2 ± 25.0	107.0 ± 23.0			
0.9125	2100 ± 220	126.4 ± 22.3	109.5 ± 22.6			
0.8875	1300 ± 180	92.4 ± 18.0	51.8 ± 15.7			
0.8625	990 ± 120	41.6 ± 14.4	59.1 ± 16.5			
0.8375	690 ± 90	65.9 ± 13.9	25.7 ± 10.5			
0.8125	520 ± 70	66.2 ± 13.3	36.8 ± 12.3			
0.775	305 ± 45	50.4 ± 8.6	58.1 ± 11.0			
0.75				2.2 ± 1.0		
0.725	115 ± 24	24.2 ± 6.5	29.3 ± 7.8			
0.675	68 ± 18	21.3 ± 6.0	30.7 ± 7.9			
0.625	50 ± 14	21.3 ± 5.4	18.4 ± 6.2			
0.575	50 ± 14	20.4 ± 5.5	22.1 ± 6.7			
0.525	48 ± 13	22.9 ± 5.0	7.8 ± 3.9			
0.50						0.7 ± 0.2
0.45	45 ± 11	12.1 ± 3.2	10.3 ± 3.3	3.5 ± 1.2		
0.35	45 ± 11	14.5 ± 3.1	7.8 ± 2.8			
0.25	48 ± 13	13.0 ± 3.3	8.8 ± 3.0			
0.15	52 ± 14	3.1 ± 2.3	13.9 ± 3.9	4.3 ± 1.4		
0.05	50 ± 14	3.6 ± 2.0	13.6 ± 3.8			
-0.10	40 ± 14	4.8 ± 1.8	13.0 ± 2.6			2.6 ± 1.6

Final state	K^-n	0^-	$\pi^- \Lambda$	0^-	$\frac{1}{2}^+$	$K^0 \Xi^-$
σ total (μb)	3400 ± 900	300 ± 32	290 ± 30	50 ± 7	49 ± 9	
$\cos \theta^*$			$d\sigma/d\Omega$ ($\mu\text{b}/\text{sr}$)			
-0.55	12 ± 7	9.1 ± 3.2	15.5 ± 4.4		4.6 ± 1.3	
-0.65	20 ± 9	17.5 ± 4.5	15.7 ± 4.7			
-0.75	28 ± 12	8.5 ± 3.2	15.3 ± 4.3	1.8 ± 0.7		
-0.825		8.5 ± 4.3	23.5 ± 8.1			
-0.85	22 ± 10				15.5 ± 2.7	
-0.875		7.7 ± 4.4	8.8 ± 4.4			
-0.925		11.3 ± 5.9	21.3 ± 7.7			
-0.95	23 ± 10					
-0.9625		22.7 ± 11.8	54.1 ± 16.5			
-0.9875		30.0 ± 13.8	114.6 ± 26.9			
t_{max}	0.0	-4.648	0.012	-4.579	0.019	-4.419
u_{max}	0.060	-4.588	0.127	-4.464	0.151	-4.287
x	t	t	u	t	u	
range	-0.105	-0.07	-0.10	-0.06	0.12	
	-0.62	-0.50	-0.16	-0.40	-0.13	
$\frac{d\sigma}{dx} = Ae^{Bx}$						
A	21000 ± 2100	610 ± 100	46 ± 12	620 ± 120	80 ± 16	
B	6.1 ± 0.3	3.4 ± 0.6	5.7 ± 0.3	5.4 ± 1.0	11.0 ± 2.0	
Ref.	[10]	[3]	[3]	[3]	[4]	

For each final state considered the maximum and minimum values of t and u are given and can be used in the change of variables $\cos \theta^*$, t , u . The table presents also the results of the fit to the formula (2) in the given x -range.

Final state	K^*n	$\rho^-\Lambda$	$\rho^0\Sigma^-$	$\omega\Sigma^-$	$\Phi\Sigma^-$	$K^{*0}\Sigma^-$
σ total (μb)	900 ± 90	285 ± 55	109 ± 9	82 ± 17	49 ± 10	30 ± 9
$\cos\theta^*$			$d\sigma/d\Omega$ ($\mu\text{b/sr}$)			
-0.15	28 ± 10	6 ± 8				0.0 ± 0.8
-0.25	6 ± 4	15 ± 9				0.0 ± 1.4
-0.30			2 ± 2	4 ± 2		
-0.35	16 ± 6	3 ± 12				2.6 ± 1.5
-0.45	16 ± 6	14 ± 8				3.6 ± 1.6
-0.50			0 ± 2	1 ± 3	0.37 ± 0.37	
-0.55	13 ± 6	2 ± 9				5.0 ± 1.9
-0.65	16 ± 6	2 ± 7				1.3 ± 0.9
-0.70			6 ± 2	3 ± 3		
-0.75	6 ± 4	11 ± 3				4.8 ± 1.9
-0.85	16 ± 6	4 ± 8				4.6 ± 1.7
-0.90			7 ± 3	12 ± 4		
-0.95	25 ± 10	32 ± 13				11.5 ± 3.0
$t_{\text{max}} t_{\text{min}}$	$-0.010 - 4.039$	$-0.031 - 3.918$	$-0.049 - 3.728$	$-0.054 - 3.691$	$-0.146 - 3.136$	$-0.147 - 3.121$
$u_{\text{max}} u_{\text{min}}$	$-0.001 - 4.031$	$0.030 - 3.856$	$0.030 - 3.649$	$0.023 - 3.615$	$-0.109 - 3.099$	$-0.058 - 3.031$
x	t	t	t			
range	$-0.06 - 0.46$	$0.13 - 0.91$	$-0.23 - 1.70$			
$\frac{d\sigma}{dx} = Ae^{Bx}$						
A	2200 ± 220	450 ± 110	110 ± 15			
B	2.9 ± 0.2	2.1 ± 0.5	1.1 ± 0.2			
Ref.	[5]			[7]	[7]	

The notations are as for table 3.

Table 5
Total and differential cross sections for the reactions $K^-n \rightarrow M(0^-) B(\frac{3}{2}^+)$

Final state	$\bar{K}^0 \Delta^-$	0^-	$\frac{3}{2}^+$
		$\pi^0 \Sigma^-(1385)$	$\eta \Sigma^-(1385)$
σ total (μb)	490 ± 60	80 ± 15	81 ± 15
$\cos \theta^*$		$d\sigma/d\Omega$ ($\mu\text{b}/\text{sr}$)	
0.975	206 ± 30		
0.95		21.7 ± 3.1	16.7 ± 5.0
0.925	244 ± 32		
0.875	146 ± 24		
0.85		19.5 ± 3.0	11.7 ± 3.0
0.825	126 ± 22		
0.75	65 ± 13	14.7 ± 2.6	5.0 ± 2.0
0.65	68 ± 13	12.0 ± 2.4	8.3 ± 3.0
0.55	35 ± 9	7.8 ± 1.9	6.7 ± 2.0
0.45	36 ± 9	5.4 ± 1.7	8.3 ± 3.0
0.35	36 ± 9	5.0 ± 1.5	6.7 ± 2.0
0.25	19 ± 8	4.1 ± 1.4	5.0 ± 2.0
0.15	27 ± 7	3.8 ± 1.4	5.0 ± 2.0
0.05	27 ± 7	3.0 ± 1.1	5.0 ± 2.0
-0.05	18 ± 9	0.5 ± 0.5	6.7 ± 2.0
-0.15	30 ± 11	3.2 ± 1.4	6.7 ± 2.0
-0.25	9 ± 6	2.6 ± 1.2	6.7 ± 2.0
-0.35	18 ± 6	2.5 ± 1.1	3.3 ± 2.0
-0.45	9 ± 6	1.0 ± 0.6	5.0 ± 2.0
-0.55	18 ± 6	7.0 ± 1.9	1.7 ± 1.7
-0.65	4 ± 4	3.4 ± 1.3	1.7 ± 1.7
-0.75		3.0 ± 1.2	3.3 ± 2.0
-0.85		3.8 ± 1.4	6.7 ± 2.0
-0.95		3.3 ± 1.4	6.7 ± 2.0
$t_{\text{max}} t_{\text{min}}$	$-0.004 -4.056$	$0.037 -3.993$	$-0.024 -3.623$
$u_{\text{max}} u_{\text{min}}$	$0.115 -3.936$	$0.215 -3.816$	$0.127 -3.472$
x	t	t	
range	$-0.05 -0.56$	$-0.06 -0.87$	
$\frac{d\sigma}{dx} = A e^{Bx}$			
A	870 ± 100	77 ± 10	
B	2.6 ± 0.3	1.2 ± 0.2	
Ref.	[5] [9]		

The notations are as for table 3.

Table 6
Total and differential cross sections for the reactions $K^-n \rightarrow M(1^-)B(\frac{3}{2}^+)$

Final state	$\bar{K}^{*0}\Lambda^-$	1^-		$\frac{3}{2}^+$
		$\rho^0\Sigma^-(1385)$	$\omega\Sigma^-(1385)$	$\Phi\Sigma^-(1385)$
σ total (μb)	1400 ± 110	$.93 \pm 13$	99 ± 24	44 ± 10
$\cos\theta^*$	$d\sigma/d\Omega$ ($\mu\text{b}/\text{sr}$)			
0.975	940 ± 71			
0.95		16.0 ± 3.6	20.8 ± 4.1	30.5 ± 6.2
0.925	579 ± 55			
0.875	393 ± 50			
0.85		15.9 ± 3.6	21.6 ± 4.1	8.3 ± 3.3
0.825	295 ± 44			
0.775	284 ± 44			
0.75		12.5 ± 3.1	14.0 ± 3.4	6.2 ± 2.9
0.725	295 ± 44			
0.675	202 ± 27			
0.65		6.7 ± 2.3	6.8 ± 2.4	4.0 ± 2.2
0.625	173 ± 27			
0.575	134 ± 22			
0.55		5.9 ± 2.2	7.0 ± 2.4	6.4 ± 2.9
0.525	126 ± 22			
0.45	86 ± 21	11.2 ± 3.0	1.7 ± 1.1	2.9 ± 1.9
0.35	84 ± 20	9.9 ± 2.7	4.6 ± 2.0	2.9 ± 1.9
0.25	63 ± 19	5.1 ± 2.0	6.4 ± 2.2	1.1 ± 1.1
0.15	43 ± 16	6.0 ± 2.2	6.0 ± 2.2	1.3 ± 1.3
0.05	40 ± 16	6.6 ± 2.2	5.1 ± 2.1	
-0.05	43 ± 11	1.8 ± 1.2	4.4 ± 2.0	
-0.15	35 ± 11	5.1 ± 2.0	2.7 ± 1.4	
-0.25	15 ± 6	7.5 ± 2.5	2.5 ± 1.4	
-0.35	23 ± 8	5.7 ± 2.0	7.1 ± 2.4	
-0.45	20 ± 8	3.7 ± 1.6	8.9 ± 2.7	0.6 ± 0.3
-0.55	23 ± 8	4.1 ± 1.8	6.8 ± 2.4	
-0.65	15 ± 6	6.3 ± 2.2	5.9 ± 2.2	
-0.75	15 ± 6	4.4 ± 2.0	7.3 ± 2.4	
-0.85	23 ± 8	8.1 ± 2.1	7.5 ± 2.4	
-0.95	5 ± 3	5.6 ± 2.0	10.3 ± 2.8	
$t_{\text{max}}\ t_{\text{min}}$	$-0.104\ -3.361$	$-0.108\ -3.229$	$-0.118\ -3.187$	$-0.320\ -2.522$
$u_{\text{max}}\ u_{\text{min}}$	$-0.035\ -3.292$	$0.017\ -3.105$	$0.004\ -3.065$	$-0.237\ -2.440$
x	t	t	t	t
range	$-0.15\ -0.39$	$-0.17\ -0.65$	$-0.19\ -0.65$	$-0.37\ -0.70$
$\frac{d\sigma}{dx} = A e^{Bx}$				
A	7450 ± 1140	97 ± 29	147 ± 40	2680 ± 2300
B	5.0 ± 0.3	1.7 ± 0.7	2.2 ± 0.6	7.6 ± 1.4
Ref.	[6]	[12]	[12]	[12]

The notations are as for table 3.

Table 7
Total and differential cross sections for some reactions $K^-n \rightarrow M(0^-) B(J^P)$

	$0^- \frac{1}{2}^-$	$0^- \frac{3}{2}^-$	$0^- \frac{5}{2}^+$
Final state	$\pi^- \Lambda(1405)$	$\pi^- \Lambda(1520)$	$\pi^- \Lambda(1815)$
σ total (μb)	100 ± 25	305 ± 30	330 ± 50
$\cos \theta^*$	$d\sigma/d\Omega$ ($\mu\text{b}/\text{sr}$)		
0.975	97.9 ± 12.0		
0.950		54.3 ± 10.1	22.3 ± 26.1
0.925	38.6 ± 7.1		
0.875	28.5 ± 6.0		
0.850		34.1 ± 7.7	2.5 ± 21.1
0.825	16.2 ± 4.5		
0.75	19.3 ± 3.5	36.1 ± 6.5	12.3 ± 18.7
0.65	8.6 ± 2.3	16.4 ± 5.5	23.4 ± 15.3
0.55	5.5 ± 1.8	13.4 ± 4.8	3.1 ± 13.4
0.45	2.3 ± 1.2	16.5 ± 4.3	12.1 ± 13.1
0.35	4.2 ± 1.6	18.5 ± 4.4	19.4 ± 12.1
0.25	0.6 ± 0.5	25.1 ± 4.2	0.0 ± 11.7
0.15	0.6 ± 0.6	15.1 ± 4.5	37.5 ± 13.0
0.05	2.4 ± 1.2	16.2 ± 4.0	27.1 ± 13.0
-0.05	3.7 ± 1.5	16.7 ± 4.5	35.3 ± 13.7
-0.15	1.2 ± 0.8	10.7 ± 3.3	29.5 ± 13.2
-0.25	0.7 ± 0.7	17.5 ± 4.1	5.0 ± 11.6
-0.35	4.8 ± 1.8	17.3 ± 4.8	23.4 ± 13.6
-0.45	4.1 ± 1.7	17.9 ± 4.6	42.4 ± 13.8
-0.55	4.2 ± 1.6	28.3 ± 5.2	25.0 ± 12.4
-0.65	3.0 ± 1.5	18.4 ± 4.3	17.1 ± 12.9
-0.75	0.6 ± 0.6	11.3 ± 4.3	23.4 ± 15.8
-0.825		19.5 ± 6.6	
-0.850	1.2 ± 1.2		67.3 ± 19.1
-0.875		42.1 ± 8.9	
-0.925		56.9 ± 10.5	70.2 ± 32.5
-0.950	1.3 ± 1.0		
-0.975		94.9 ± 13.3	132.2 ± 37.4
$t_{\text{max}} t_{\text{min}}$	$0.039 - 3.944$	$0.052 - 3.652$	$0.085 - 2.793$
$u_{\text{max}} u_{\text{min}}$	$0.222 - 3.762$	$0.266 - 3.438$	$0.381 - 2.487$
x range	t $-0.01 - 0.31$	t u -0.04 0.22 $-0.60 - 0.20$	u $0.36 - 0.11$
$\frac{d\sigma}{dx} = Ae^{Bx}$			
A	300 ± 33	200 ± 35 101 ± 12	113 ± 40
B	6.3 ± 0.6	1.8 ± 0.5 5.1 ± 0.7	4.4 ± 1.3
Ref.	[19]	[8] [2]	[8] [19]

The notations are as for table 3.

3.2. Differential cross sections

For each reaction where the statistics are large enough to allow the determination of the angular distribution the differential cross section $d\sigma/d\Omega$ in the c.m. system is presented in tables 3 – 7 and figs. 2 – 6, versus $\cos\theta^*$ ‡.

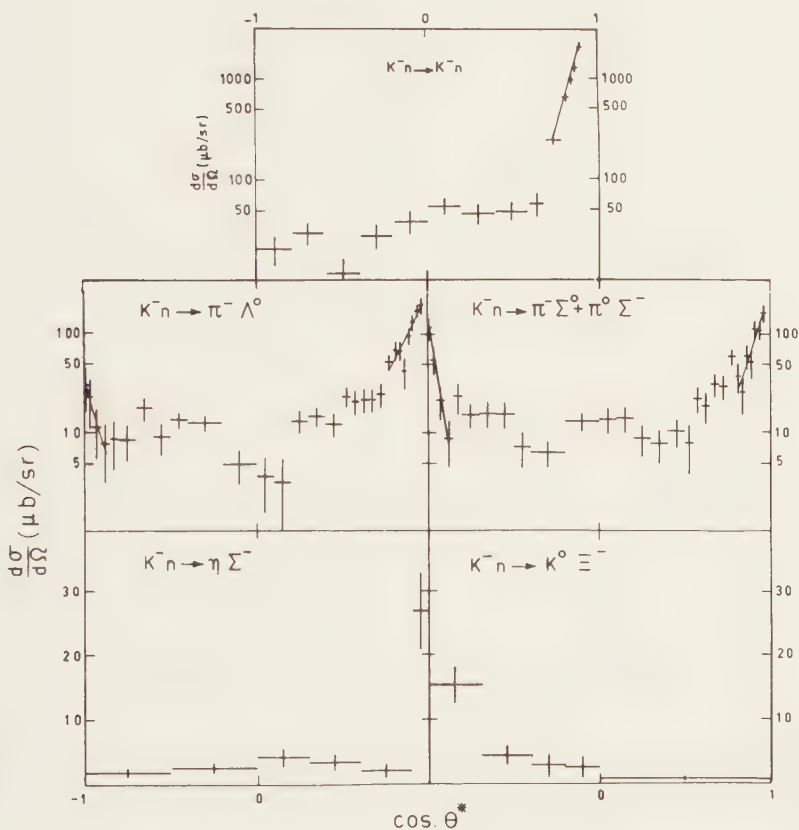


Fig. 2. Differential cross section of the reactions presented in table 3.

‡ The main reason for using $\cos\theta^*$ instead of t (or u) as a variable is due to the fuzzing of $t(u)$ for large values of $t(u)$ caused by the Fermi momentum in the deuterium target. The forward (backward) differential cross section is almost proportional to $d\sigma/dt$ ($d\sigma/du$).

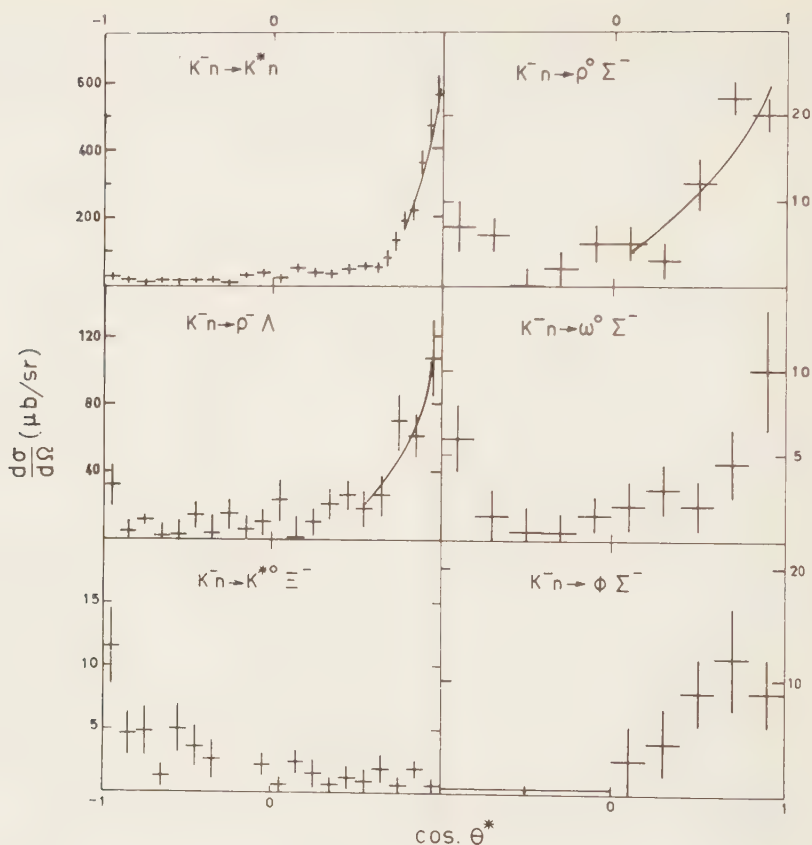


Fig. 3. Differential cross section of the reactions presented in table 4.

For each reaction the maximum and minimum values of t and u are also given; they can be used in the transformation of $d\sigma/d\Omega$ to $d\sigma/dt$ or $d\sigma/du$. When the forward (or backward) peak was sufficiently prominent the forward (backward) cross section has been fitted to the formula

$$\frac{d\sigma}{dx} = Ae^{Bx}, \quad (2)$$

where x stands for t or u^* . The A - and B -parameters, as well as the $t(u)$ range used

* One should note that A represents the value of $d\sigma/dt$ ($d\sigma/du$) extrapolated at $t = 0$ ($u = 0$). The value of $d\sigma/dt$ ($d\sigma/du$) at $t_{\max}$ ($u_{\max}$) may be derived from the data of the table.

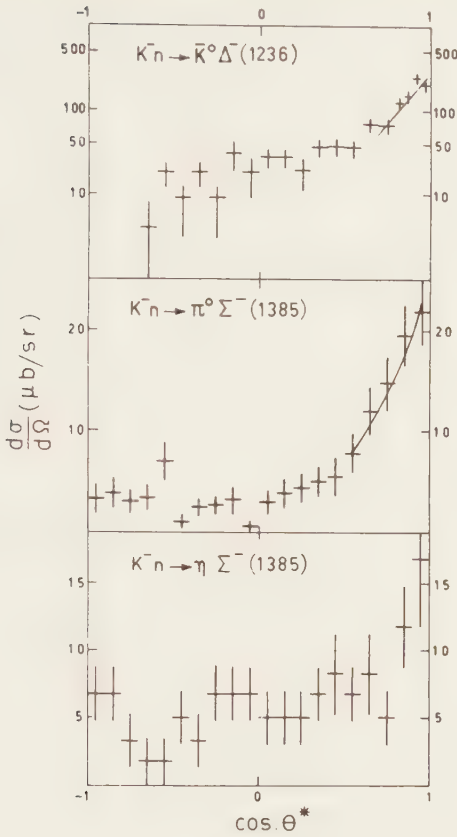


Fig. 4. Differential cross section of the reactions presented in table 5.

for their determination, are presented after the differential cross section. Finally the reference to the paper dealing with the detailed analysis of the reaction are also given.

3.3. Density matrix

Tables 8 - 10 present the density matrix elements ρ_{ij} for the reactions type $1-\frac{1}{2}^+$, $0-\frac{3}{2}^+$ and $1-\frac{3}{2}^+$ respectively. The ρ_{ij} are determined in the Jackson frame of the vector meson, or $\frac{3}{2}^+$ baryon, as a function of $\cos \theta^*$ except for $0-\frac{3}{2}^+$ reactions where they have been averaged over the angular distribution.

Table 11 gives the Λ polarization in the $\pi^- \Lambda$ reaction as a function of t .

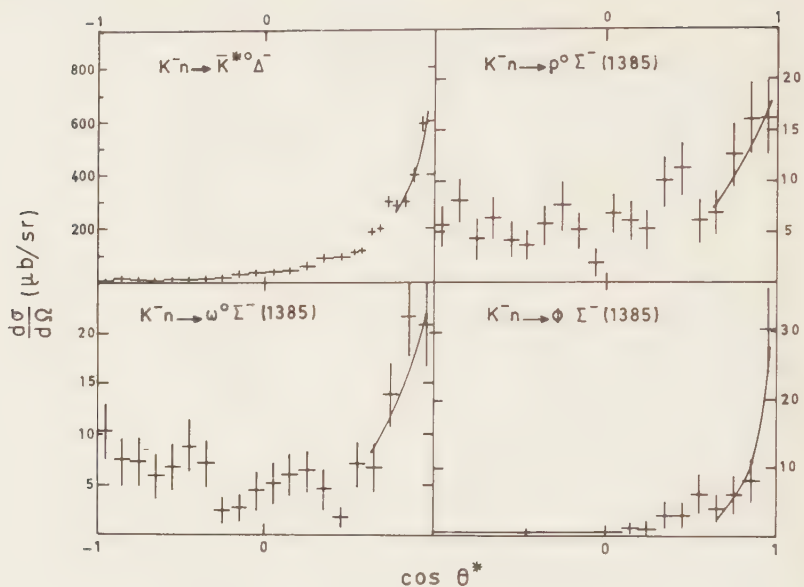


Fig. 5. Differential cross section of the reactions presented in table 6.

4. COMMENTS

Although the incident momentum seems sufficiently low that the interactions in the s -channel could still be present, the differential cross sections presented below display the forward and backward peaking generally associated with high-energy behaviour. The intermediate angular region, which generally corresponds to small differential cross sections, does not show evident structures. In this section we will survey the general features of these distributions, within the frame of t - and u -channel exchanges.

4.1. Forward scattering

4.1.1. Shape of the forward peak. Except for the reactions where only an exotic meson can be exchanged, all distributions (except $\Lambda(1815)\pi$) are peaked forward. The slopes of the peak range from ≈ 1 $(\text{GeV}/c^2)^{-2}$ to ≈ 6 $(\text{GeV}/c^2)^{-2}$ implying different mechanisms for the forward scattering. In general it seems difficult to correlate this slope with the nature of the exchanged meson, except in the elastic case, where $B \approx 6$ $(\text{GeV}/c^2)^2$ is characteristic of a diffraction mechanism, and in the reactions where π -exchange is assumed to be dominant, such as $K^-p \rightarrow \bar{K}^*{}^0 n$ and

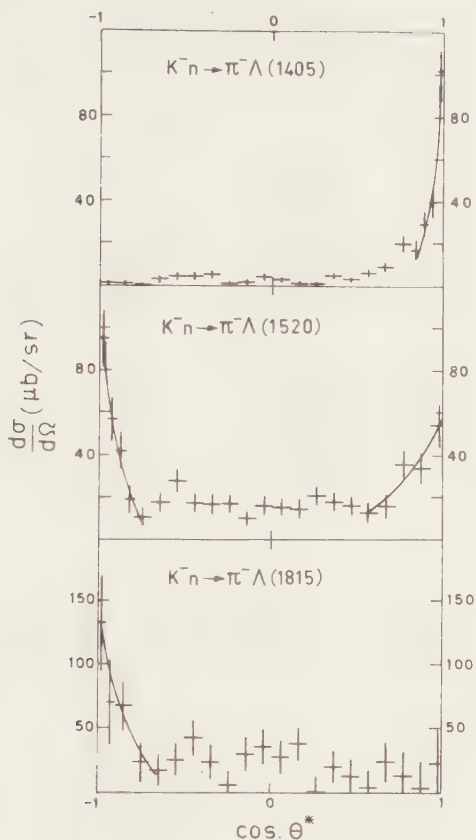


Fig. 6. Differential cross section of the reactions presented in table 7.

$n \rightarrow \bar{K}^{*0} \Delta^-$ where $B \approx 5.5 \text{ (GeV}/c^2)^2$. For instance in the πY reactions, which are supposed to be dominated by K^* , K^{**} exchange, the spread of the slope is considerable.

A somewhat more constant feature of the shape of the peak is the presence of a change of slope in the t -region $0.5 \leq |t| \leq 0.7$ for almost all reactions. This feature is generally interpreted as arising from the zero in the natural parity meson trajectories occurring at $t \approx -0.5$. It should be noted that the ratio between $(d\sigma/dt)_{\max}$ and $d\sigma/dt$ for $t \approx 0.7$ ranges from ≈ 100 (for elastic scattering) to ≈ 4 for reactions with $\Sigma(1385)$ in the final state. Thus it is not clear if the differential cross section above $t \approx 0.7$ can still be described by a t -channel mechanism.

Table 8
Density matrix elements for the reactions $K^-n \rightarrow M(1^-) B(\frac{1}{2}^+)$ in the Jackson frame

Final state	$\cos \theta^*$	ρ_{00}	$\rho_{1,-1}$	$\text{Re } \rho_{1,0}$
$K^{*-}n$	0.95 ± 0.05	0.40 ± 0.07	0.10 ± 0.07	-0.09 ± 0.03
	0.85 ± 0.05	0.24 ± 0.10	0.29 ± 0.08	-0.06 ± 0.06
	0.40 ± 0.40	0.09 ± 0.08	0.32 ± 0.08	0.03 ± 0.06
$\rho^0 \Sigma^-$	0.85 ± 0.15	0.15 ± 0.09	0.30 ± 0.08	0.03 ± 0.07
	0.20 ± 0.50	0.16 ± 0.07	0.44 ± 0.07	-0.04 ± 0.06
	-0.65 ± 0.35	0.21 ± 0.11	0.08 ± 0.10	-0.04 ± 0.10
$\omega \Sigma^-$	0.90 ± 0.20	0.17 ± 0.10	0.18 ± 0.10	-0.02 ± 0.09
	0.525 ± 0.275	0.27 ± 0.08	0.39 ± 0.08	-0.08 ± 0.07
	-0.10 ± 0.35	0.26 ± 0.11	0.20 ± 0.11	-0.22 ± 0.10
	-0.725 ± 0.275	0.29 ± 0.11	-0.04 ± 0.10	-0.12 ± 0.10
$\phi \Sigma^-$	0.85 ± 0.15	0.20 ± 0.10	0.27 ± 0.12	0.10 ± 0.09
	0.35 ± 0.35	0.01 ± 0.09	0.39 ± 0.09	-0.05 ± 0.08

Table 9
Density matrix elements for the reactions $K^-n \rightarrow M(0^-) B(\frac{3}{2}^+)$ in the Jackson frame

Final state	$\langle \rho \rangle$ $\rho_{3,3}$	$\text{Re } \rho_{3,-1}$	$\text{Re } \rho_{3,1}$
$\bar{K}^0 \Delta^-$	0.29 ± 0.04	0.26 ± 0.05	-0.09 ± 0.05
$\pi^0 \Sigma^-(1385)$	0.41 ± 0.05	0.08 ± 0.07	-0.07 ± 0.06
$\eta^0 \Sigma^-(1385)$	0.30 ± 0.15	0.15 ± 0.08	0.00 ± 0.10

4.1.2. *Isospin decomposition in the t -channel.* Except for reactions in which the final baryon or meson has isospin zero, and for the production of $I = \frac{3}{2}$ baryon (Δ) two t -channel isospin amplitudes can contribute to the interaction. The knowledge of K^-p and K^-n reactions allows in principle the separation of these two amplitudes. We will thereafter show the result of this separation, for non strange and strange meson exchange.

(i) Reactions $\bar{K}N \rightarrow \bar{K}N$ and $\bar{K}N \rightarrow \bar{K}^*N$. The two pure isospin $I_t = 0$ and $I_t = 1$ differential cross sections of these reactions can be derived as

$$\frac{d\sigma}{dt}(I_t=0) = 2 \frac{d\sigma}{dt}(K^-p \rightarrow K^{-(*)}p) + 2 \frac{d\sigma}{dt}(K^-n \rightarrow K^{-(*)}n) - \frac{d\sigma}{dt}(K^-p \rightarrow \bar{K}^{0(*)}n),$$

Table 10
Density matrix elements for the reactions $K^-n \rightarrow M(1^-)B(\frac{3}{2}^+)$ in the Jackson frame

Final state	$\cos\theta^*$	ρ_{00}	$\rho_{1,-1}$	$\text{Re } \rho_{1,0}$	$\rho_{3,3}$	$\text{Re } \rho_{3,-1}$	$\text{Re } \rho_{3,1}$
$\bar{K}^{*0}\Delta^-$	0.98 ± 0.02	0.61 ± 0.05	0.00 ± 0.04	-0.03 ± 0.03	0.05 ± 0.03	0.04 ± 0.03	0.05 ± 0.04
	0.93 ± 0.03	0.60 ± 0.05	-0.01 ± 0.03	0.07 ± 0.03	0.08 ± 0.03	-0.03 ± 0.03	-0.01 ± 0.04
	0.85 ± 0.05	0.46 ± 0.05	0.01 ± 0.03	0.03 ± 0.03	0.11 ± 0.03	0.07 ± 0.03	0.05 ± 0.04
	0.65 ± 0.15	0.40 ± 0.04	0.05 ± 0.03	0.03 ± 0.02	0.16 ± 0.03	0.03 ± 0.02	-0.08 ± 0.04
$\rho^0\Sigma^-(1385)$	0.9 ± 0.10	0.30 ± 0.13	-0.09 ± 0.13	0.01 ± 0.10	0.35 ± 0.10	-0.02 ± 0.11	0.11 ± 0.09
	0.65 ± 0.15	0.60 ± 0.15	-0.16 ± 0.12	0.14 ± 0.09	0.14 ± 0.10	0.05 ± 0.09	0.02 ± 0.10
	0.25 ± 0.25	0.69 ± 0.11	-0.02 ± 0.07	0.01 ± 0.08	0.24 ± 0.08	0.07 ± 0.07	0.01 ± 0.09
	-0.50 ± 0.50	0.22 ± 0.08	0.10 ± 0.07	0.00 ± 0.05	0.19 ± 0.06	0.11 ± 0.06	0.07 ± 0.05
$\omega^0\Sigma^-(1385)$	0.90 ± 0.10	0.80 ± 0.16	-0.02 ± 0.08	-0.16 ± 0.07	0.00 ± 0.10	-0.09 ± 0.08	-0.01 ± 0.12
	0.65 ± 0.15	0.66 ± 0.12	-0.08 ± 0.09	-0.08 ± 0.07	0.00 ± 0.08	0.06 ± 0.07	0.18 ± 0.09
	0.25 ± 0.25	0.30 ± 0.13	-0.13 ± 0.10	0.02 ± 0.09	0.25 ± 0.10	0.09 ± 0.11	0.08 ± 0.10
	-0.50 ± 0.50	0.38 ± 0.09	-0.07 ± 0.07	-0.14 ± 0.05	0.32 ± 0.06	0.04 ± 0.07	0.20 ± 0.06
$\phi\Sigma^-(1385)$	0.875 ± 0.125	0.60 ± 0.16	-0.05 ± 0.13	0.18 ± 0.10	0.00 ± 0.12	-0.07 ± 0.10	0.44 ± 0.13
	0.375 ± 0.375	0.46 ± 0.19	0.02 ± 0.14	0.09 ± 0.10	0.10 ± 0.14	0.17 ± 0.12	0.16 ± 0.10

Table 11
Distribution of the Λ polarization P_Λ for the reaction $K^-n \rightarrow \pi^-\Lambda$

$-t$	$\cos \theta^*$	P_Λ
0.025 ± 0.025	0.984	0.04 ± 0.25
0.100 ± 0.050	0.951	0.11 ± 0.26
0.200 ± 0.050	0.908	0.93 ± 0.31
0.350 ± 0.100	0.842	0.64 ± 0.30
0.650 ± 0.200	0.712	0.59 ± 0.30
1.225 ± 0.375	0.461	1.12 ± 0.30
2.350 ± 0.750	-0.029	0.18 ± 0.34
3.525 ± 0.425	-0.541	-0.83 ± 0.33
4.250 ± 0.300	-0.856	-0.17 ± 0.50

$$\frac{d\sigma}{dt}(I_t=1) = \frac{d\sigma}{dt}(K^-p \rightarrow \bar{K}^0(*)n). \quad (3)$$

This decomposition has already been published for the first reaction [10]. As expected the forward diffraction peak in elastic scattering is essentially associated with the $I_t = 0$ contribution which is 2 orders of magnitude larger near $t = 0$ than that for $I_t = 1$.

The differential cross sections $(d\sigma/d\Omega)(I_t=0)$ and $(d\sigma/d\Omega)(I_t=1)$ of the reaction $\bar{K}N \rightarrow \bar{K}^*(890)N$ are shown on fig. 7. The $I_t = 0$ differential cross section shows a definite dip in the forward direction, whereas the $I_t = 1$ distribution, which is about 3 times smaller, presents a steep forward peak, as already mentioned.

(ii) Reactions $\bar{K}N \rightarrow MY$. The comparison of the forward cross section for the exotic t -channel reactions $K^-p \rightarrow M^+Y^-$ and the non exotic ones $K^-p \rightarrow M^-Y^+$ and $K^-n \rightarrow M^0Y^0$ leads to a determination of the σ_3/σ_1 ratio, σ_3 and σ_1 being the forward cross sections corresponding to $I_t = \frac{3}{2}$ and $I_t = \frac{1}{2}$ exchanges in the t -channel

$$\frac{\sigma_3}{\sigma_1} = \frac{3}{4} \frac{\sigma_{M^+Y^-}}{2\sigma_{M^-Y^+} + \sigma_{M^0Y^0} - \frac{2}{3}\sigma_{M^+Y^-}}. \quad (4)$$

In table 12 it can be seen that this ratio is of the order of 3% but it should be stressed that this value is obtained from events in the whole forward hemisphere. Due to s -channel contribution, these values probably represent upper limits. For the first reaction, which is free of background, a similar determination made for the region $\cos \theta^* > 0.8$, leads to a smaller value of σ_3/σ_1 .

4.2. Backward scattering

The main characteristics of the backward scattering are:

(i) In the reactions requiring an exotic exchange in the u -channel (K^-n, K^*n) no

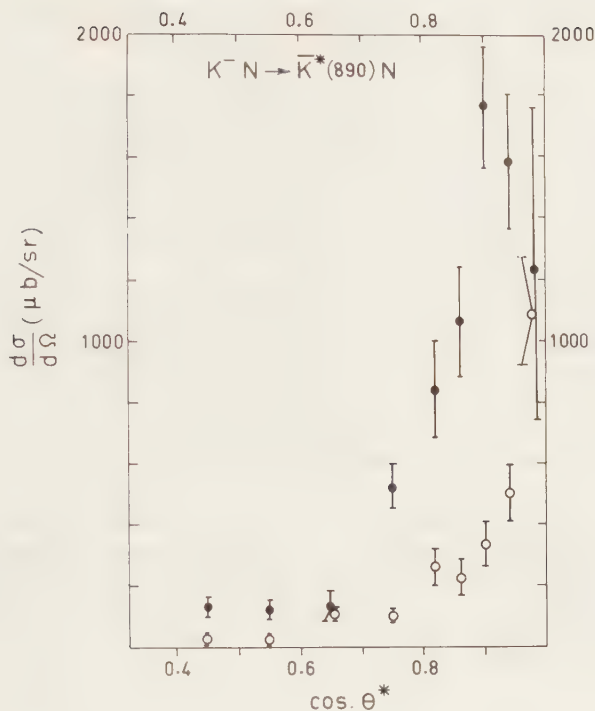


Fig. 7. Differential cross sections of the $I_t = 0$ part (black points) and $I_t = 1$ part (empty points) of the reactions $\bar{K}N \rightarrow \bar{K}^*(890)N$.

Table 12

Reaction	σ_3/σ_1	
	$\cos \theta^* > 0$	$\cos \theta^* > 0.8$
$\bar{K}N \rightarrow \pi\Sigma$	$(19 \pm 7) \times 10^{-3}$	$(4.6 \pm 2.3) \times 10^{-3}$
$\bar{K}N \rightarrow \rho\Sigma$	$(30 \pm 15) \times 10^{-3}$	
$\bar{K}N \rightarrow \pi\Sigma(1385)$	$(36 \pm 10) \times 10^{-3}$	
$\bar{K}N \rightarrow \rho\Sigma(1385)$	$(25 \pm 15) \times 10^{-3}$	

peak has been observed. More quantitatively in the $K^-n \rightarrow K^-n$ reaction an integrated cross section of $36 \pm 12 \mu\text{b}$ is obtained for $u > -0.6 (\text{GeV}/c^2)^2$. This result and the corresponding one deduced from the reaction $K^-p \rightarrow \bar{K}^0n$ ($0 \pm 2 \mu\text{b}$) and from the pure $I_u = 1$ reaction $K^-p \rightarrow K^-p$ ($8 \pm 4 \mu\text{b}$) leads to a value of $64 \pm 24 \mu\text{b}$ for the $I_u = 0$ cross section.

(ii) On the other hand in the reactions where the t -channel is exotic, the angular distribution is dominated by a strong backward peak.

(iii) In the reactions where t - and u -channel exchanges are possible one can see in table 1 that the ratio σ_B/σ_F increases with the mass of the final baryon; this variation is essentially related to the increase of $u_{\max}$ with this mass. Thus the presence of a backward peak is generally well observed in reactions with a large $u_{\max}$, where a non strange baryon can be exchanged as in the $Y\pi$ and YV final states (here V stands for a vector meson) as well as in those where a strange baryonic state occurs in the u -channel (ΞK and $\Xi^* K$ final states).

Although the statistics are limited it appears that this peak is followed by a dip around $u = -0.2$ in the $Y\pi$ final states; such a dip is not apparent in YV reactions where a minimum could occur around $u = -0.9$. The first dip at $u = -0.2$ which is well known in the π^+p backward elastic scattering has been interpreted by the exchange of the N_α trajectory [16]. A simple interpretation of the $Y\pi$ backward scattering in terms of nucleon exchange has been reported recently for these reactions [8].

However, the u -channel exchange mechanism can be rather involved, due to the many possible exchanged trajectories. Furthermore, although the absence of backward peaks in the reactions $\Sigma^-\Phi$ and $\Sigma^-(1385)\Phi$ has been explained in terms of the quark model, the same absence in the reactions $\Lambda(1405)\pi$, $\Sigma(1385)\pi$, $\Sigma(1385)V$ is not even qualitatively understood.

5. CONCLUSION

From a qualitative analysis of the (quasi) two-body reaction cross sections and angular distributions, the following general remarks emerge:

- (i) The angular distributions are dominated by forward and(or) backward peaks whenever the meson or baryon states to be exchanged are not exotic.
- (ii) The main characteristic features of the angular distributions are:
 - (a) a change of the forward peak slope in the t -region $0.5 \leq |t| \leq 0.7$;
 - (b) the presence of a dip around $u = -0.2$ (GeV/c^2)² in the $K^-n \rightarrow Y\pi^-$ backward scattering.
- (iii) The upper limit of cross sections for exotic exchange in the t -channel has been shown to be at least two order of magnitude lower than the cross section for non exotic exchange. This indicates that the s -channel contribution in the forward direction is very small.

All these features have been analysed by means of standard meson and baryon exchange models, but in general only semi quantitative agreement has been obtained. Therefore, it seems clear that the possibility of explaining these data by more general and elaborate models remains completely open.

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BARYON EXCHANGE IN THE REACTIONS $K^-n \rightarrow Y\pi^-$ AT 3 GeV/c

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Abstract: At 3 GeV/c, the total and differential cross sections of the reactions $K^-n \rightarrow Y\pi^-$ have been determined for nine $S = -1$ baryonic states. Backward peaks associated with a dip near $u = -0.2$ are observed in many cases. They have been interpreted, for the isospin-zero Y -states, in terms of a proton-exchange mechanism. The backward peaks in the reactions $K^-n \rightarrow \Lambda\pi^-$ and $K^-n \rightarrow \Sigma^0\pi^-$ have been more quantitatively related to the backward $\pi N \rightarrow N\pi$ differential cross sections at the same energy. This comparison leads to the conclusion, that the first reaction is dominated by nucleon exchange, whereas the second one requires a more complex exchange mechanism.

1. INTRODUCTION

In a study of reactions of the type $K^-n \rightarrow Y\pi^-$ at 3 GeV/c, where Y represents a baryonic state of strangeness -1, narrow backward peaks are observed in most of the π^- production angular distributions. The effect is particularly prominent in reactions where Y is an isospin-zero hyperon - the only exception being $\Lambda(1405)$ - and where the u -channel therefore is in

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a pure isospin $I_M = \frac{1}{2}$ state. It is assumed that the backward peaks for these reactions can be interpreted in terms of a single-proton exchange model. Indeed, the decay angular distributions of the unstable Y_0 are shown to be compatible with such an assumption. In this approximation we may then determine the relative values of the coupling constants $G_{Y_0 K^- p}^2$, where Y_0 stands for $\Lambda(2100)$, $\Lambda(1815)$, $\Lambda(1690)$, $\Lambda(1520)$ and $\Lambda(1115)$.

Finally we attempt to compare more quantitatively the backward differential cross sections of the reactions $\bar{K}N \rightarrow \Lambda\pi$ and $\bar{K}N \rightarrow \Sigma\pi$ with those of $\pi N \rightarrow N\pi$ by assuming SU(3) invariance. The value of $G_{\Lambda K^- p}^2 / G_{N N \pi}^2$ is extracted from the comparison of the $I_M = \frac{1}{2}$ backward cross sections of the first and third reactions. The $I_M = \frac{3}{2}$ $\bar{K}N \rightarrow \Sigma\pi$ and $\pi N \rightarrow N\pi$ backward cross sections are found to be compatible with the SU(3) predictions.

2. EXPERIMENTAL DATA

The data presented in this paper come from a 7 event/ μb K^-d exposure taken at 3 GeV/c with the 80 cm Saclay bubble chamber at CERN. A detailed description of this experiment and a determination of the cross sections of all separated final states has been previously published [1]. We shall concentrate here on the study of the reactions

$$K^- n \rightarrow Y\pi^-, \quad (1)$$

where Y is a baryonic state of strangeness -1, with isospin 0 or 1. These reactions are extracted from the following final states:

$$K^- n \rightarrow K^- p \pi^- \quad (2) \quad 920 \pm 60 \mu\text{b},$$

$$K^- n \rightarrow \bar{K}^0 n \pi^- \quad (3) \quad 1600 \pm 110 \mu\text{b},$$

$$K^- n \rightarrow \Sigma^+ \pi^- \pi^- \quad (4a) \quad 270 \pm 26 \mu\text{b},$$

$$K^- n \rightarrow \Sigma^- \pi^+ \pi^- \quad (4b) \quad 340 \pm 25 \mu\text{b},$$

$$K^- n \rightarrow \Lambda \pi^0 \pi^- \quad (5) \quad 760 \pm 96 \mu\text{b},$$

$$K^- n \rightarrow \Lambda \pi^- \quad (6) \quad 300 \pm 32 \mu\text{b},$$

$$K^- n \rightarrow \Sigma^0 \pi^- \quad (7a) \quad 160 \pm 22 \mu\text{b},$$

$$K^- n \rightarrow \Sigma^- \pi^0 \quad (7b) \quad 130 \pm 20 \mu\text{b}.$$

The number following each reaction indicates the relevant cross section [1]. No serious problem occurs in the separation of these final states*.

* The separation of reactions (7) events has been achieved as described in ref. [2]. In particular only $\Sigma^0 \pi^-$ events for which the squared missing mass recoiling against the $\Lambda [MM^2(\Lambda)]$ is larger than 0.35 GeV^2 have been selected in the $d\sigma/du$ distribution. But reaction (6) events used in this study were those fitting this reaction and for which $MM^2(\Lambda) < m_\pi^2$; the contamination of $\Sigma^0 \pi^-$ events being negligible in this sample, one avoids the subtraction procedure utilized in ref. [2] which gives rise to too large errors in the backward direction.

However it should be noted that a small contamination of $\Sigma^0\pi^-\pi^0$ events is present in the reaction (5) sample.

3. MASS SPECTRA OF THE Y-SYSTEM AND PRODUCTION CROSS SECTIONS

The mass spectra of the systems K^-p (reaction (2)), $\bar{K}^0n$ (reaction (3)) and $\Sigma^\pm\pi^\mp$ (reactions (4)) are displayed in fig. 1 (1, b, c). In reaction (5), due to isospin invariance, the two mass distributions $\Lambda\pi^-$ and $\Lambda\pi^0$ should be identical; however as the experimental resolution of the $\Lambda\pi^-$ mass spectrum is much better than that of $\Lambda\pi^0$, we shall hereafter replace the neutral system $\Lambda\pi^0$ by $\Lambda\pi^-$, whose mass spectrum is presented in fig. 1d.

In the fig. 1 spectra, one may observe the presence of most of the well-known Y-resonances, which are listed in the first column of table 1. Al-

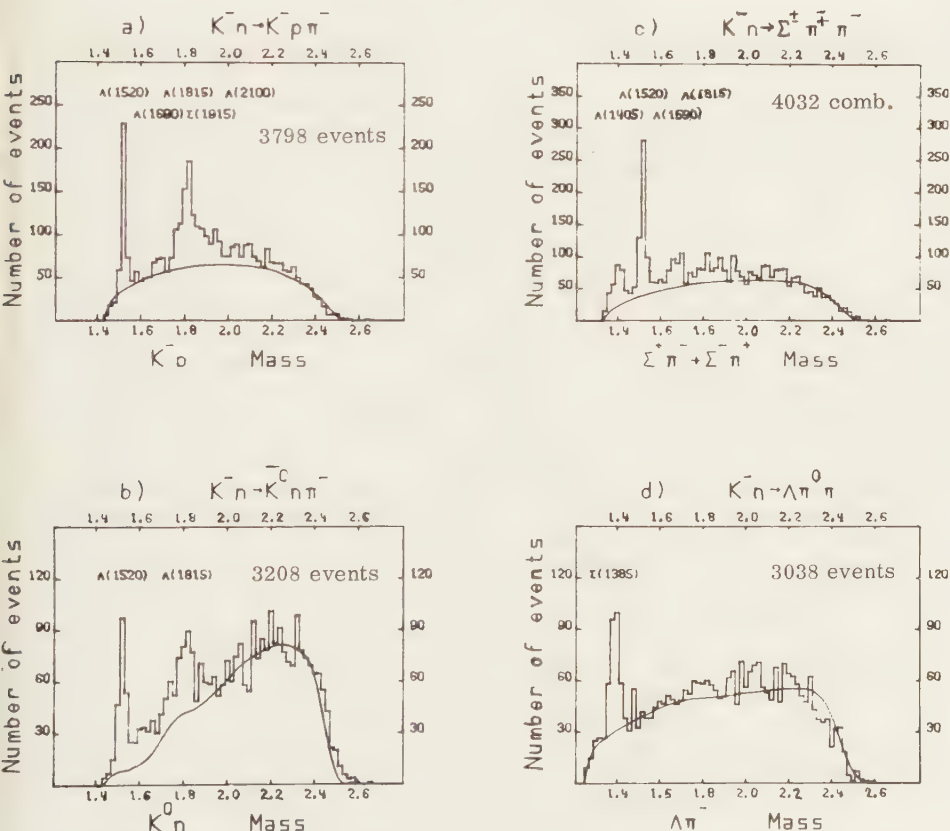


Fig. 1. Weighted mass spectra of the systems K^-p , $\Sigma^+\pi^- + \Sigma^-\pi^+$, $\bar{K}^0n$ and $\Lambda\pi^-$. The plotted curve is a background calculated by taking into account phase space and the reflections of the most strongly produced resonances.

Table 1

Y ($I_z=0$)	Observed mass (MeV)	Observed width (MeV)	Reaction partial cross section (μb)			$\Sigma\pi/\bar{\text{K}}\text{N}$ observed branching ratio	Total cross section (μb) ($I_z=0$)	Backward ($u>0$) cross section (μb)
			$\text{K}^-\text{p}\pi^-$	$\bar{\text{K}}^0\text{n}\pi^-$	$(\Sigma^+\pi^-\pi^-)$ + $(\Sigma^-\pi^+\pi^-)$			
$\Lambda(2100)$	2120 ± 20	90 ± 30	32 ± 7	38 ± 20	12 ± 8	0.26 ± 0.20	210 ± 70	175 ± 65
$\Lambda(1815)$	1815 ± 10	50 ± 15	117 ± 20	99 ± 13	16 ± 7	0.11 ± 0.06	370 ± 50	136 ± 30
$\Lambda(1690)$	1680 ± 10	45 ± 15	13 ± 6	10 ± 7	33 ± 10	2.15 ± 1.00	100 ± 60	30 ± 20
$\Lambda(1520)$	1520 ± 10	< 20	64 ± 7	70 ± 11	88 ± 10	0.99 ± 0.12	290 ± 25	75 ± 15
$\Lambda(1405)$	1400 ± 10	60 ± 15			65 ± 15		100 ± 25	< 3
$\Lambda(1115)$							300 ± 32	10 ± 2
$\Sigma(1915)$	1920 ± 20	80 ± 10	30 ± 15		< 10		600 ± 350	200 ± 120
$\Sigma(1385)$	1385 ± 10	50 ± 10					100 ± 20	1 ± 1
$\Sigma(1190)$							160 ± 22	24 ± 5

though the evidence for some of these resonances is rather vague in the spectra, their significance will be enhanced later on by applying appropriate cuts. No evidence for the presence of $\Sigma(1760)$ is observed. It should be pointed out that the Y are not the only resonances produced in reactions (2)-(5); in particular $K(888)$ and $\Delta(1238)$ are strongly produced in reaction (3), while ρ -production is present in reactions (4b) and (5). However the Y-production is the main resonance production in reaction (2), in which $\Delta(1238)$ is only weakly produced ($\sigma \approx 60 \mu\text{b}$) (ref. [3]); thus the final state $K^- p \pi^-$ will constitute our best sample for this analysis.

The cross sections for Y-production in each of these final states are presented in table 1. The branching fractions that follow are in good agreement with the accepted values [4]. The total Y-production cross sections presented in table 1 include all the unmeasured decay channels and were calculated from their partial cross sections in reaction (2) with the aid of the branching fractions of ref. [4].

4. PRODUCTION OF THE Y-SYSTEM ASSOCIATED WITH BACKWARD π^-

The production angular distribution of the π^- in the reactions (1) is characterized by a strong forward peaking. An analysis of this peripheral process in terms of strange meson exchange has been made for reactions (6) and (7) (ref. [5]).

In this paper, we shall concentrate on the backward region of the π^- production angular distribution, where a definite peak is observed in most of these reactions. This is clearly illustrated in the Chew-Low plot of reaction (2) presented in fig. 2, where u (the square of the four-momentum transfer between the incident K^- and the final Y-system *) is plotted against the mass of the Y-system. The density in the plot is quite high for $u \geq 0$ and increases with u up to the limit u_{max} . As this limit is larger for the higher masses of the Y-system, rising to a value of 0.6 GeV^2 for $M_Y = 2.1 \text{ GeV}$, the production of heavy Y appears to be enhanced. This is evident in fig. 3, where the mass spectra of the Y-system are presented in the region $(0.15 < u < 0.50)$ for reactions (2)-(5) and in the region $(0.30 < u < 0.50)$ for reaction (2) only. In reactions (2), (3) and (4), the Y-peaks emerge more strongly above background than in fig. 1, except for $\Lambda(1405)$ which is not present in the first u -region ($u_{\text{max}} = 0.22$ for $\Lambda(1405)$). The enhancement is especially important (fig. 3e) for the $\Lambda(2100)$ peak having $M = 2120 \pm 20 \text{ MeV}$ and $\Gamma = 90 \pm 30 \text{ MeV}$, which is clearly seen in the region $u > 0.3$, and for the peak located at 1920 MeV , which could be assigned to $\Sigma(1915)$. In the region $0.15 < u < 0.50$ the peak located at $M = 1680 \pm 10$ and $\Gamma \approx 50 \pm 15$ (figs. 3a, 3c) seems more likely to be $\Lambda(1690)$ than $\Sigma(1660)$ although a mixture of both states is possible. From fig. 3d one may also conclude that backward production of $\Sigma(1385)$ is negligible.

* The quantity u is calculated here from the $\cos \theta^*$ (c.m. production angle) distribution of the π^- in the $Y\pi^-$ c.m. system, by assuming a fixed neutron target; the effect of the neutron motion in the deuteron causes a negligible dispersion of u for $u \geq 0$.

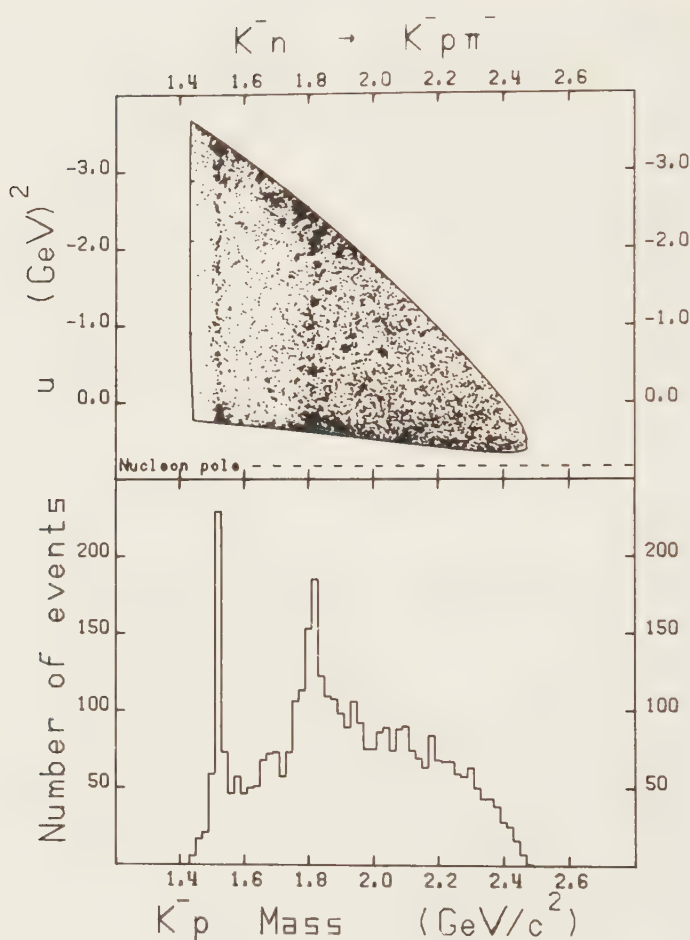


Fig. 2. Chew-Low plot of reaction $K^-n \rightarrow K^-p\pi^-$ and K^-p mass projection.

5. $d\sigma/du$ DISTRIBUTIONS OF Y ($I=0$) SYSTEMS

The $d\sigma/du$ distributions as far as $u = -1.0 \text{ GeV}^2$ are given in fig. 4 for the reactions leading to $I=0$ Y -systems:

$$K^-n \rightarrow \pi^- \Lambda(1115), \quad (6)$$

$$K^-n \rightarrow \pi^- \Lambda(1520), \quad \Lambda(1520) \rightarrow \bar{K}N, \Sigma^\pm \pi^\mp, \quad (8)$$

$$K^-n \rightarrow \pi^- \Lambda(1690), \quad \Lambda(1690) \rightarrow \bar{K}N, \Sigma^\pm \pi^\mp, \quad (9)$$

$$K^-n \rightarrow \pi^- \Lambda(1815), \quad \Lambda(1815) \rightarrow \bar{K}N, \quad (10)$$

$$K^-n \rightarrow \pi^- \Lambda(2100), \quad \Lambda(2100) \rightarrow K^-p, \quad (11)$$

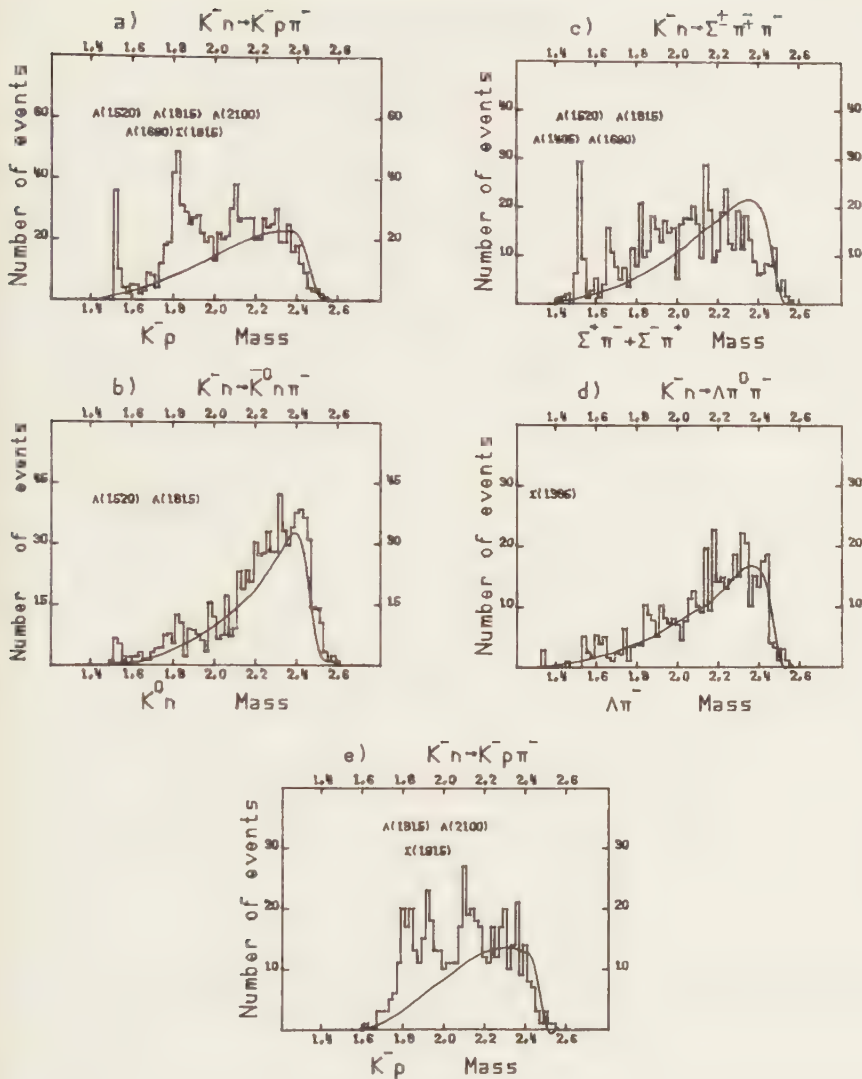


Fig. 3. Weighted mass spectra of the systems K^-p , $\Sigma^+\pi^- + \Sigma^-\pi^+$, $\bar{K}^0n$ and $\Lambda\pi^-$ for events selected in the u -region $0.15 < u < 0.50$ (a, b, c, d) and of the system K^-p for events selected in the u -region $0.30 < u < 0.50$ (e). The plotted curve is a background calculated by taking into account phase space and the reflections of the most strongly produced resonances.

The $d\sigma/du$ distributions have been normalized to the total $Y\pi$ cross sections given in table 1. In all $d\sigma/du$ distributions, a peak near $u_{\max}$ is visible, a feature which obviously suggests that baryon exchange plays an important role. Moreover, one may notice an indication of a dip near $u = -0.20$, for all these reactions. As the u -channel is in a pure $I = \frac{1}{2}$ state, this effect reminds one of that observed in the $d\sigma/du$ distribution of high-

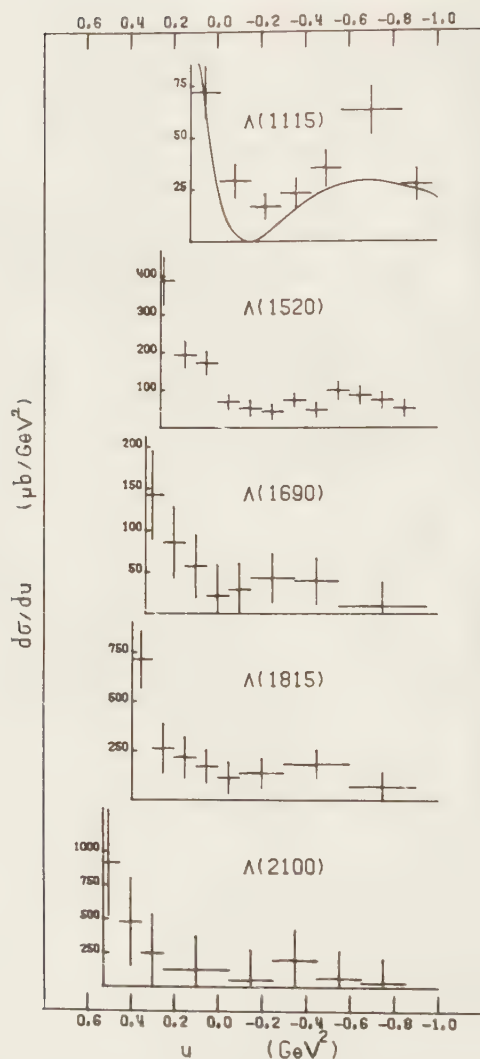


Fig. 4. Differential cross sections $d\sigma/du$ for the reactions $K^-n \rightarrow Y$ ($I=0$) π^- where Y stands successively for $\Lambda(1115)$, $\Lambda(1520)$, $\Lambda(1690)$, $\Lambda(1815)$ and $\Lambda(2100)$. The curve shown in the $K^-n \rightarrow \Lambda\pi^-$ differential cross section is a prediction at 3 GeV/c of Martin and Michael.

energy π^+p elastic scattering (incident momenta between 3 and 16 GeV/c), where the dip has been attributed to the vanishing of the contribution of the N_α trajectory [6]. This feature of the data indicates rather strongly that the backward scattering in this group of reactions is dominated by a proton exchange mechanism. The relatively large backward $d\sigma/du$ differential cross section for heavy Y such as $\Lambda(1815)$ and $\Lambda(2100)$ can then be explained by their relative proximity to the proton pole as indicated in fig. 2.

6. DECAY ANGULAR DISTRIBUTION OF THE Υ -RESONANCE

In the case of a pure proton exchange mechanism, the decay angular distribution of the $I=0$ Υ produced in the forward direction is simply a function of their total angular momentum J if one neglects interference effects with background. In fig. 5 we present the distribution of $\cos \theta^* = (\hat{K}_{in}^-, \hat{K}_{out}^-)_{Y_{0c.m.}}$ for the $\Lambda(1520)$ and the $\Lambda(1815)$ as obtained in reaction (2) with $u > -0.15$. A background evaluated on each side of the $\Lambda(1520)$ and the $\Lambda(1815)$ peaks has been subtracted. The agreement with the expected distribution respectively for $J = \frac{3}{2}$ and $J = \frac{5}{2}$, represented by the solid line, is quite good for both. More quantitatively, the normalized Legendre polynomial expansion coefficients A_n/A_0 are compared in table 2 with their expected values. One can then conclude that the hypothesis of a spin $\frac{1}{2}$ baryon is compatible with the data.

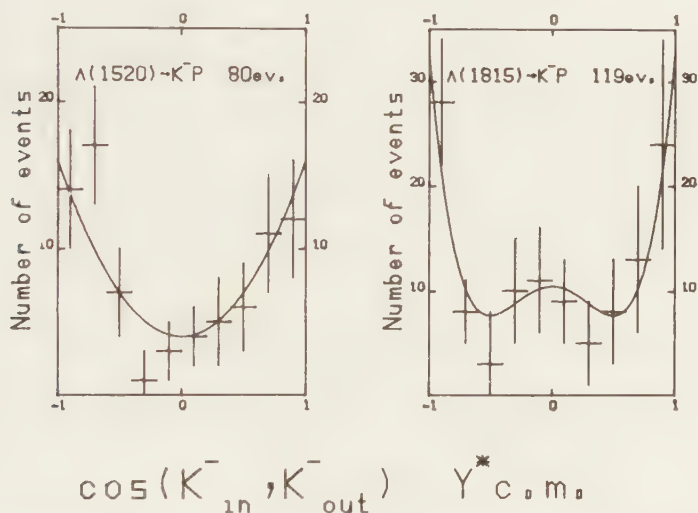


Fig. 5. Decay angular distribution of $\Lambda(1520)$ and $\Lambda(1815)$ as obtained in reaction (1) with $u > -0.15$. The curve represents the distribution predicted by a pure proton exchange mechanism.

Table 2

	$\Lambda(1520) \frac{3}{2}^-$		$\Lambda(1815) \frac{5}{2}^+$	
	theor.	exp.	theor.	exp.
A_1/A_0	0.0	-0.17 ± 0.21	0.0	0.03 ± 0.24
A_2/A_0	1.0	1.14 ± 0.24	$\frac{8}{7}$	1.06 ± 0.29
A_3/A_0			0.0	-0.09 ± 0.38
A_4/A_0			$\frac{6}{7}$	1.29 ± 0.40

7. DETERMINATION OF THE RELATIVE VALUES OF THE COUPLING CONSTANT $G_{Y_0 K^- p}^2$

Under the assumption of a single-proton exchange mechanism the backward differential cross section can be written as [7]:

$$\frac{d^2\sigma}{dM_Y du} \approx f(u) M_Y^2 Q_{\text{off}}^2 \sigma_{\text{off}}(M_Y),$$

where M_Y is the mass of the Y-system, Q_{off} the incident K^- momentum in the Y-rest system, $f(u)$ the propagator function, and σ_{off} the total $K^- p$ off-mass-shell cross section. As with the Dürr-Pilkühn [8] corrections which were applied successfully [9] in the one-pion-exchange model, the 'off-mass-shell' cross section has been related to the 'on-mass-shell' cross section by

$$\frac{(Q\sigma)_{\text{off}}}{(Q\sigma)_{\text{on}}} = \frac{B_{l, \text{off}}}{B_{l, \text{on}}}.$$

Here $B_{l, \text{off}}$ and $B_{l, \text{on}}$ are the usual centrifugal barrier factors calculated respectively with the off-mass-shell (Q_{off}) and the on-mass-shell (Q_{on}) momenta. The interaction radius has been chosen somewhat arbitrarily at $R = 0.5$ fm and $R = 1$ fm.

In the case of a resonant Y_0 system having a mass M_{Y_0} , a spin J corresponding to an orbital angular momentum l , and total and partial $K^- p$ widths Γ and $\Gamma_{K^- p}$, one obtains after integration over M_Y (in the narrow width approximation):

$$\frac{d\sigma}{du}_{Y_0} \approx (J + \frac{1}{2}) f(u) \frac{\Gamma_{K^- p}}{Q_{\text{on}}} M_{Y_0}^2 \frac{B_{l, \text{off}}}{B_{l, \text{on}}},$$

since

$$\sigma_{\text{on}} \approx \frac{(J + \frac{1}{2})}{Q_{\text{on}}^2} \frac{\Gamma \Gamma_{K^- p}}{4(M_{Y_0} - M_Y)^2 + \Gamma^2}.$$

We use the following expression given by Tripp [10] to relate the coupling constant $G_{Y_0 K^- p}$ to the partial width $\Gamma_{Y_0 K^- p}$:

$$\Gamma_{Y_0 K^- p} = G_{Y_0 K^- p}^2 B_{l, \text{on}} Q_{\text{on}} \frac{M_n}{M_{Y_0}},$$

where M_n is the nucleon mass. Then

$$\frac{d\sigma}{du}_{Y_0} \approx (J + \frac{1}{2}) f(u) M_{Y_0} B_{l, \text{off}} G_{Y_0 K^- p}^2.$$

Thus the square of the coupling constant of the resonant Y_0 system to $K^- p$ is proportional to $(d\sigma/du)_{Y_0}/(J + \frac{1}{2}) M_{Y_0} B_{l, \text{off}}$ for the resonances produced at the same value of u . In practice, the ratio of the coupling constants $G_{Y_0 K^- p}^2/G_{\Lambda(1815) K^- p}^2$ for each resonance listed in table 3 are averaged in

Table 3

Y_0	Γ_{K^-p} (MeV)	u -range	$G_{Y_0 K^-p}^2 / G_{\Lambda(1815) K^-p}^2$			
			$R = 0.5 \text{ fm}$		$R = 1 \text{ fm}$	
			from $d\sigma/du$	from Γ_{K^-p}	from $d\sigma/du$	from Γ_{K^-p}
$\Lambda(2100)$	11.3	0.0 - 0.375	0.95 ± 0.25	0.74 ± 0.20	0.40 ± 0.15	0.36 ± 0.10
$\Lambda(1815)$	24.4					
$\Lambda(1690)$	4.5	0.0 - 0.325	0.15 ± 0.10	0.05 ± 0.02	0.40 ± 0.10	0.14 ± 0.05
$\Lambda(1520)$	3.7	0.0 - 0.275	0.80 ± 0.15	0.41 ± 0.10	1.65 ± 0.20	0.64 ± 0.20
$\Lambda(1115)$		0.0 - 0.125	0.65 ± 0.10		2.00 ± 0.25	

a suitable u range. These values are then compared with those extracted directly from the $\Gamma_{Y_0 K^-p}$ partial widths listed in the first column, by using the same interaction radius $R = 0.5 \text{ fm}$ or $R = 1 \text{ fm}$.

Due to the general inaccuracy of the determination of coupling constants, the agreement between the quantities presented in table 3 can be considered as satisfactory for the resonant Y_0 states. This provides another argument for the validity of the proton exchange mechanism in the u -channel. One may also relate the coupling constant $G_{\Lambda K^-p}^2$ to the various $G_{Y_0 K^-p}^2$. Although this relation depends somewhat on the assumed interaction radius the qualitative result is that the ratio $G_{\Lambda K^-p}^2 / G_{\Lambda(1815) K^-p}^2$ is of the order of unity.

The absence of forward production of $\Lambda(1405)$ would lead to a value of $G_{\Lambda(1405) K^-p}^2 / G_{\Lambda(1815) K^-p}^2 < 0.10$. This seems to be in contradiction both with the SU(3) prediction [10] and with results from low-energy K^-p elastic scattering [11]; this could imply a more complicated production mechanism.

8. COMPARISON BETWEEN $\pi N \rightarrow \pi N$, $\bar{K}N \rightarrow \Lambda\pi$ AND $\bar{K}N \rightarrow \Sigma\pi$ BACKWARD SCATTERING NEAR 3 GeV/c

Other than the possible antiperipheral production of $\Sigma(1915)$ seen in fig. 3 (a, e), the only $I = 1$ Y strongly produced via a baryon exchange mechanism is $\Sigma(1190)$. This is evident from fig. 6, where $d\sigma/du$ of the reactions

$$K^-n \rightarrow \Sigma^0(1190)\pi^-, \quad (7a)$$

$$K^-n \rightarrow \Sigma^0(1385)\pi^-, \quad (12)$$

are presented. The presence of a dip near $u = -0.2$ in the $d\sigma/du$ distribution of reaction (7a) may also be noted.

In these reactions $I = \frac{1}{2}$ and $I = \frac{3}{2}$ baryons can be exchanged in the u -channel, and a simple interpretation of the backward differential cross sections is no longer possible. However, in the case of reaction (7), the knowledge

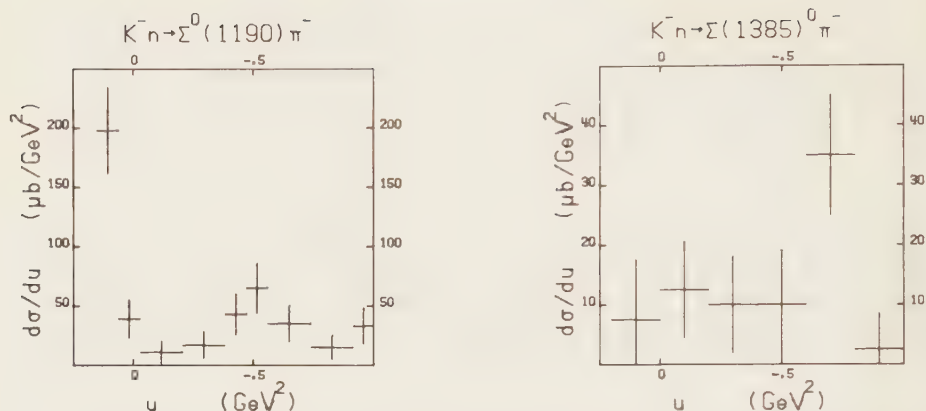


Fig. 6. Differential cross section $d\sigma/du$ for the reaction $K^-n \rightarrow Y(I=1)\pi^-$ where $Y(I=1)$ stands successively for $\Sigma^0(1190)$ and $\Sigma(1385)^0\pi^-$.

at the same incident momentum [12] of the differential cross sections for the reactions $K^-p \rightarrow \Sigma^\pm \pi^\mp$ allows an isospin decomposition in the u -channel. A quantitative comparison can then be made between $\pi N \rightarrow N\pi$, $\bar{K}N \rightarrow \Lambda\pi$, $\bar{K}N \rightarrow \Sigma\pi$ backward scattering, where all interacting baryons and mesons are members of the well-known $\frac{1}{2}^+$ and 0^- $SU(3)$ octets.

The backward cross sections of the πN reactions

$$\pi^+p \rightarrow p\pi^+, \quad (13)$$

$$\pi^-p \rightarrow n\pi^0, \quad (14)$$

$$\pi^-p \rightarrow p\pi^-, \quad (15)$$

have been measured over a large range of incident momenta, especially in the 3-4 GeV/c region [6]. In order to make a quantitative comparison we define the backward cross sections as

$$B = \int_{-0.1}^{0.1} \frac{d\sigma}{du} du.$$

In each of the three groups of reactions having respectively a Λ , a Σ or a nucleon in the final state, one may express the cross sections for both $I_u = \frac{1}{2}$ and $I_u = \frac{3}{2}$ u -channel isospin states as follows:

$$B_{\Lambda}^{\frac{1}{2}} = \frac{3}{2} B(\Lambda\pi^-),$$

$$B_{\Sigma}^{\frac{1}{2}} = \frac{3}{2} [B(\Sigma^-\pi^+) + B(\Sigma^0\pi^-) - \frac{1}{3} B(\Sigma^+\pi^-)],$$

$$B_N^{\frac{1}{2}} = \frac{3}{2} [B(p\pi^+) + B(n\pi^0) - \frac{1}{3} B(p\pi^-)],$$

$$B_{\Sigma}^{\frac{3}{2}} = B(\Sigma^+ \pi^-) ,$$

$$B_{\text{N}}^{\frac{3}{2}} = B(\text{p} \pi^-) .$$

In fig. 7 are presented, in addition to our results, recent $\pi\text{N} \rightarrow \text{N}\pi$ (refs. [13, 14]) $\text{K}^-\text{n} \rightarrow \Lambda\pi^-$ (ref. [15]) and $\text{K}^-\text{p} \rightarrow \Sigma^\pm \pi^\mp$ (ref. [12]) 'backward' cross sections, as well as calculated values of $B_{\Sigma}^{1/2}$ and $B_{\text{N}}^{1/2}$ as a function of S , the square of the c.m. energy.

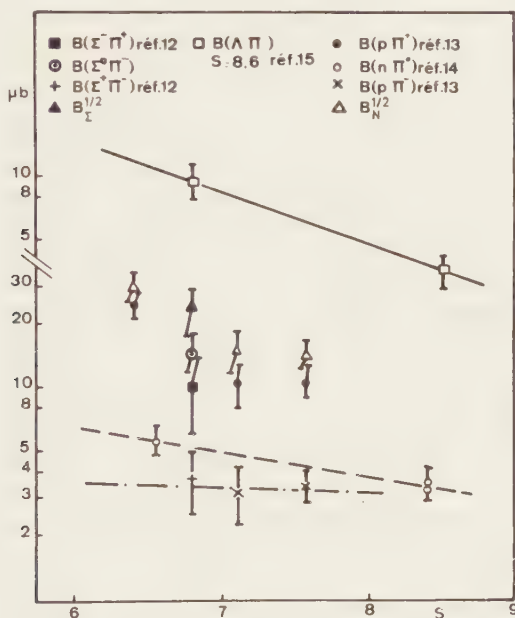


Fig. 7. Values of the backward cross section for the reactions $\pi\text{N} \rightarrow \text{N}\pi$, $\text{K}^-\text{n} \rightarrow \Lambda\pi^-$ and $\text{K}^-\text{N} \rightarrow \Sigma\pi$ as a function of the square of the c.m. energy S . The values $B_{\text{N}}^{\frac{3}{2}}$ and $B_{\Sigma}^{\frac{3}{2}}$ have been obtained by the relation described in the text.

If one assumes that all the $I = \frac{3}{2}$ baryons exchanged in the u -channel belong to a decuplet, then $\text{SU}(3)$ symmetry requires that the amplitudes corresponding to all these exchanges be the same in reaction $\text{K}^-\text{p} \rightarrow \Sigma^+ \pi^-$ and in reaction (15). Neglecting all kinematical factors other than p_{π}^{*2} and p_{K}^{*2} (the square of the πN and $\bar{\text{K}}\text{N}$ c.m. momenta respectively due to the difference of meson masses) one can then write

$$\frac{B_{\Sigma}^{\frac{3}{2}}}{B_{\text{N}}^{\frac{3}{2}}} = \left(\frac{p_{\pi}^*}{p_{\text{K}}^*} \right)^2 \approx 1.1 \quad \text{at} \quad S = 6.8.$$

The experimental ratio 1.12 ± 0.35 at $S = 6.8$ ($p_K = 3$ GeV/c) agrees very well with this prediction.

On the other hand, $I = \frac{1}{2}$ baryon exchange in the u -channel does not lead to such a simple SU(3) prediction, as the $\alpha = D/(F+D)$ ratios of the exchanged octets are generally different. Thus each nucleon (or nucleon trajectory) provides contributions to the ΛK , ΣK and πN channels which are relatively different.

Under the assumption of dominance of $\frac{1}{2}^+$ octet exchange, the ratio between the coupling constants $G_{\Lambda K^- p}^2$, $G_{\Sigma^0 K^- p}^2$ and $G_{NN\pi}^2$ can be obtained from the relations

$$\frac{G_{\Lambda K^- p}^2}{G_{NN\pi}^2} = 3 \left(\frac{p_K^*}{p_\pi^*} \right)^2 \frac{B_{\Lambda}^{\frac{1}{2}}}{B_N^{\frac{1}{2}}},$$

$$\frac{G_{\Sigma^0 K^- p}^2}{G_{NN\pi}^2} = \left(\frac{p_K^*}{p_\pi^*} \right)^2 \frac{B_{\Sigma}^{\frac{1}{2}}}{B_N^{\frac{1}{2}}}.$$

From the data presented in fig. 7, the $I_u = \frac{1}{2}$ backward cross sections ratio have been determined at $S = 6.8$:

$$\frac{B_{\Lambda}^{\frac{1}{2}}}{B_N^{\frac{1}{2}}} = 0.43 \pm 0.13, \quad \frac{B_{\Sigma}^{\frac{1}{2}}}{B_N^{\frac{1}{2}}} = 1.10 \pm 0.30.$$

The first ratio leads to a value of $G_{\Lambda K^- p}^2/G_{NN\pi}^2 = 1.17 \pm 0.35$ which is within the range of the numerous determinations of this quantity [16] and corresponds to a value of $\alpha(\frac{1}{2}^+) = D/(F+D)$ equal to 0.57. Similarly the second ratio would give a value of $G_{\Sigma^0 K^- p}^2/G_{NN\pi}^2 \approx 1$, in disagreement with most of the previous determinations of this quantity, and would lead to a value of α incompatible with 0.57. This discrepancy has been explained by Barger and Michael [17] who pointed out that the admixture of other exchanged octets in the u -channel does not perturbate appreciably the first ratio, whereas it could modify strongly the second.

A similar result has been obtained by Martin and Michael [18][†] who have fitted the background differential cross sections of reactions (6) at 3.9 GeV/c (ref. [15]) and of reactions (13)-(15) between 3.5 and 6 GeV/c by means of a Regge model including only the N_α trajectory in the $I_u = \frac{1}{2}$ channel. This fit, which also gives a ratio $G_{\Lambda K^- p}^2/G_{NN\pi}^2 \approx 1$, is presented for 3 GeV/c in fig. 4. This prediction is in very good agreement with the experimental data. However, due to the more complex situation in reaction (7), no acceptable fit can be obtained from πN u -channel amplitudes.

[†] We thank these authors who gave us their prediction for the different cross section $K^- n \rightarrow \Lambda \pi^-$ at 3 GeV/c.

9. CONCLUSION

In conclusion we would like to summarize the following points:

(i) The $d\sigma/du$ distributions of the reactions $K^-n \rightarrow Y\pi^-$, where Y is an $I=0$ hyperon, exhibit, except for $\Lambda(1405)$, a backward peak with a shape comparable to that observed in π^+p elastic scattering. The qualitative agreement between the decay angular distributions of the $\Lambda(1520)$ and $\Lambda(1815)$, and the distributions predicted by pure proton exchange, suggest that this mechanism is responsible for the presence of the backward peak. Under this hypothesis, the $Y_0 K^-p$ coupling constants, extracted from the backward differential cross sections, are in good agreement with the accepted values of these quantities. It seems worthwhile to note that in the exchange degeneracy model of Schmid [19], the states $\Lambda(2100)$, $\Lambda(1815)$, $\Lambda(1520)$ and $\Lambda(1115)$, which lie on a single degenerate Regge trajectory, should have the same large coupling constant to K^-p , whereas all others should have smaller coupling constants. These four states appear to be strongly produced in our experiment through a proton exchange mechanism, whereas the other $I=0$ resonances are produced weakly ($\Lambda(1690)$) or not at all ($\Lambda(1405)$) in the same conditions.

(ii) The $I=1$ hyperon states are generally not produced in association with a backward π^- , except for $\Sigma(1190)$ and its Regge recurrence $\Sigma(1915)$. But in this case, the $I_u = \frac{1}{2}$ amplitude is no longer dominated by the exchange of a proton, as expected by the Schmid model, and the coupling constant $G_{\Sigma}^2 K^-p$ cannot be determined in this way.

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